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RIVER-BED SCOUR DURING FLOODS

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RIVER-BED SCOUR DURING FLOODS

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In the design of the project for the protection and rehabilitation of the Middle Rio Grande Valley in New Mexico, the question of how deep the river beds scoured during floods assumed a position of unusual importance. A study was therefore made to determine its magnitude. The circumstances which led to the importance of the scour depth are given in the following paragraphs:

CONDITIONS IN THE MIDDLE RIO GRANDE VALLEY

Before the intense agrarian use of this area by white settlers, the Middle Rio Grande Valley had probably reached a status which approached an equilibrium condition in which the sediment carried out of the valley nearly equalled the sediment brought into it by the Rio Grande and its tributaries. In recent years, however, a large portion of the upstream runoff has been used for irrigation, thus decreasing the stream flow in this downstream Middle Rio Grande Valley. Overgrazing of the watershed, in addition, has increased the sediment load brought into the main stream by the tributaries. There is some evidence that a secular change of climate may also be partly responsible. Thus the load of sediment brought into the valley has increased, and the flow to carry it out has decreased, with the result that the valley is filling up at a rate which the latest measurements indicate to be about 1 inch per year. The river bed at Albuquerque, the principal city of the valley, is already above the level of the streets. This condition not only increases the danger of floods but also tends to raise the ground-water level on the agricultural land of the valley and threatens it with waterlogging. Also water-loving plants have grown up in the abandoned areas and are increasing the nonbeneficial use of the water to an extent that seriously decreases the available water supply. The rise of the river bottom is thus seriously threatening the future prosperity of the valley.

To remedy this condition, a plan of improvement, developed jointly by the Bureau of Reclamation and the Corps of Engineers, was approved by the Congress. The plan consists principally of the construction of: (1) two storage dams for the storage of sediment and temporary retention of flood flows, and (2) channel control works to cause the channel to scour out and thus lower its bed. The storage of sediment in the basins behind the dams and the release of the clarified water into the river channel below is expected to cause a lowering of the river bed, due to the picking up of the bed material by the clarified water. A stream-bed degradation of considerable magnitude through this process has taken place below Lake Mead on the lower Colorado River due to the release of clarified water from that lake. As will be shown later, the rate at which the degradation will take place in the Rio Grande Valley is related to the depth to which the river bed of this stream scours during floods. It was very important, therefore, to study this phenomenon.

Observations on the lowering of the river bed below Lake Mead indicate that when the clarified water is released from the dams on the Rio Grande, the flow will carry away a larger proportion of the finer particles in the bed than coarser particles. As a result the particle size composition of the bed material will gradually become more coarse. For example, Figure 1 shows the increase in size of the bed material in the lower Colorado River at Section 8, which is located a short distance below Hoover Dam. Since a given river flow cannot carry as large a volume of coarse as of fine material, this coarsening of the bed will cause the river to carry away a continually smaller amount of material as time passes. There will thus be a gradual reduction of the rate of degradation, and after a certain period of time, the rate of lowering of the bed will be negligible. The rate at which the fine sand is removed and the length of time before the degradation rate becomes negligible depends upon the depth to which the river bed is scoured during high flows, since the amount of fine material which can be removed by the river depends upon the amount of this material which comes in contact with the flowing water and, thus, can be carried away. If the depth of scour is small, only a little fine material can be carried away before the bed becomes covered with coarse material; however, if the depth is great, a large amount will be carried away before the bottom becomes too coarse. The removal of the small amount in the case of the small depth of scour will lower the bed much less than the removal of the large amount if the depth of scour is great. Therefore, it was necessary to know whether the depth of scour will be small or large.

The Middle Rio Grande is a steep stream having a slope of about 4-1/2 feet per mile in the vicinity of Albuquerque, New Mexico, and it carries a heavy sediment load averaging at San Marcial about 1.18 percent by weight. It is wide, shallow, and relatively straight. The channel is frequently divided by islands, or takes what is known as a braided pattern. It is wide and shallow in some stretches, but narrower and deeper in others. In many respects it resembles numerous other rivers found in the western United States.

THE COMMONLY ACCEPTED IDEA OF DEPTH OF SCOUR

Over the past 40 years, the discharges of the Rio Grande and other similar rivers in the western states have been measured thousands of times in high and low water conditions. In each of these observations, the cross section was determined by frequent soundings across the stream bed. It has been observed at these measurement sections that usually as the flow of water in the stream increases, the average depth of the flowing water increases more than the water surface level rises. This indicates that the bottom of the stream has been scoured out. It is not uncommon for the bottom to deepen as much as the water surface rises. When the flood crest is passed and the flow decreases, the bottom begins to fill in, and when the flood has passed, the bottom has risen substantially back to the level which existed before the flood. This is shown by Figure 2 which gives the changes which took place in the river bed at the San Marcial gaging station on the Rio Grande during the year 1929.

Similar changes have been observed so frequently in the Rio Grande and other western rivers that it is the general impression of many experienced river men in the western states that this is a general action of the channel for streams of this type. They believe that when a flood occurs the bed of the stream, at least for the greater part of its length and width, scours down materially and refills as the flood recedes. This is an opinion widely held by

men who have gaged the Rio Grande. This opinion is substantiated by observations of the effect that the floods exert on driven pilings for bank protection work, in which these pilings are observed to rise suddenly in the water and float away despite the fact that they are 40-feet long with most of this length below the stream bottom. It has also been noted that bridges supported by 60-foot pilings have been washed out during such floods. If such deep scour takes place over the whole stream bottom during floods, the volume of river bed material from which the finer particles can be drawn is very great, and a long time will elapse before the coarsening of the bottom caused by the clear water from the proposed sediment control reservoirs will stop the degradation of the stream bed.

CONFLICT OF THE GENERALLY ACCEPTED IDEA OF SCOUR WITH VOLUME OF SEDIMENT DEPOSITED IN RESERVOIRS

The belief of many experienced stream gagers and other local observers that the whole bed of the Rio Grande scours deeply during floods seems to be based on quite conclusive evidence; but a quantitative examination proves even more conclusively that such deep general scour has not occurred during floods in recent years. If the Rio Grande scours down several feet over substantially its entire width and length, it must move a very large quantity of material down the river. Practically all of the material transported in the section of stream under study is deposited in the Elephant Butte Reservoir. Frequent measurements have been made of the volume of sediment being deposited in this basin, and the amount is known within reasonable accuracy. When this amount is compared with that which would have to be moved into the reservoir with an average depth of scour over the river bed of even a small depth, say 1.5 feet, the amount actually deposited is very much less than would occur with this scour. We thus have the apparently conflicting evidence of the scour unquestionably observed by the stream gagers and the unquestionable lack of a corresponding amount of material deposited in the reservoir.

In quantitative terms this difference may be shown as follows: The section of the Rio Grande from Cochiti to San Marcial has a length of 160 miles and an average width of 1,170 feet, giving it a surface area of 22,700 acres. For each foot of average depth of scour below the elevation of the bed at the start of the flood, a volume of 22,700 acre-feet would, therefore, be carried into the lake. The average amount of material carried into the lake per year is 18,276 acre-feet, of which only about 1,800 acre-feet are composed of sand and larger sizes, such as would be scoured out of the stream bottom. Since floods sufficient to scour the river bed occur practically every year, it is evident that the average depth of scour during floods, even if all the deposited coarse material is assumed to be moved out of the bed, is of the order of magnitude of only 0.08 feet.

Another proof of the nonexistence of large depths of scour over substantially the whole of the stream-bed area is that the measurements of sediment concentration made in the river do not show the presence of sufficiently large amounts of sand to account for so great scour of the channel bed. For a flood to scour out an average of 5 feet of depth from the bed of the Rio Grande would require that it move 113,500 acre-feet of sediment, practically all sand, from the river bed. The concentrations in the Rio Grande below the mouth of the Puerco may reach as high as 20 percent concentration due largely to flash floods from the Rio Puerco, which is probably the carrier of the highest sediment concentration of any stream in the United States, and possible the world,

68 percent by weight having been observed in it.[1] Above the mouth of the Puerco concentrations in the Rio Grande rarely reach above 5 percent. These high concentrations are of short duration and only a small part of them is composed of sand particles. Although the sand loads are high, no flows have been observed at the lower end of the river with sufficient volume of discharge and concentration of sand sizes to account for near the 113,500 acre-feet transport necessary to deepen the river bed an average of 5 feet. Since after a flood the river bed refills again as the flood recedes, an inflow of 113,500 acre-feet of sand would be required to provide this material, but no such flows have been observed. Moreoever, if this scouring action took place, at the lower end of the valley there would be a very high concentration of sand during the first part of the flood but a very large flow with very low concentration during the latter part of the flood. A high sediment concentration during the early part of the flood is commonly observed, but the concentration differences between rising and falling floods are insufficient to account for extensive general scour.

Dr. L. G. Straub has made extensive studies of the changes of river bed level due to contractions, including both model studies and observations on the Missouri River.[2] As a result he reached the conclusion that the scour observed at contracted sections was not general throughout the length of the river.

A GENERAL STUDY OF SCOUR IN RIVER BEDS

Since the data available on depth of scour in the Rio Grande were so conflicting that no satisfactory quantitative values would be obtained, it was decided to make a general study of the available literature bearing on this subject with a view to obtaining more light on this point. The following paragraphs are a summary of the principal information brought out by this investigation.

The study disclosed that very few measurements for the primary purpose of determining general bed scour have been made. Most of the data available have been secured from measurements made primarily for other purposes, such as stream discharge or surveys to determine depths available for navigation. Observations of local scour, such as those at bridge piers or abutments, are of no value in determining the general bed scour with which this study is concerned. The available data seem to deal with two general classes of rivers: large rivers of small or moderate slope, like the Mississippi and the Missouri, and smaller rivers of steep slope, such as one frequently finds in the western United States.

The situation in these two types of streams differ somewhat. The larger rivers, if they flow in alluvial beds, generally consist of a series of bends between which are stretches of more or less straight river. In the straight sections the main channel of the river usually crosses from one side of the river to the other; and the location of this changeover is called a crossing. At ordinary stages the bends are usually deep and relatively narrow, and the crossings are wider and more shallow.[3]

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1. Sedimentation Studies in Conchas Reservoir, New Mexiso - D. C. Bondurant, ASCE Separate No. 29, August 1950, p. 10.
2. Transactions of the American Geophysical Union 1934, Part II, p. 454; also House Document No. 238, 73d Congress, 2nd Session, Appendix XV, p. 1150.
3. A Laboratory Study of the Meandering of Alluvial Rivers--J. F. Friedkin--United States Waterways Experiment Station.

In Figure 3 are shown diagrammatically (A) a typical cross section of a large river at a bend and (B) a typical cross section at a crossing. The water level at medium stages is represented by the lines b and b' and at high and low discharges by a and a' and c and c', respectively. At medium stages the cross-sectional area of flow is about the same in both cases, and the velocity of flow is consequently also about the same. In floods the water level rises to a and a', a rise of approximately the same height above b and b'. Because the width in the crossing is considerably greater than in the bend, the rise of water level increases the cross section in the crossing more than in the bend; and, therefore, makes the total cross-sectional area at the crossing greater than at the bend. This difference causes a lower velocity at the crossing than at the bend; and therefore, tends to produce less scour in the crossing than in the bend. At the low-water stage the opposite action occurs. The areas at the bends become larger than at the crossings, and more scour takes place on the crossings. At high-water stages, then, the pools usually scour out; and at the crossings deposition occurs, while during low-water stages, the crossings scour out and the bends fill up.

The Rio Grande is a relatively straight river and does not have the bend and crossing form characteristics of the large alluvial rivers, but it does have a series of alternately narrow and wide sections. If the river has approximately the same area in both types of sections at normal flows, then during floods it should have larger areas at the wide sections and smaller areas at the narrow ones, thus producing deposit at the wide sections and scour at the narrow ones, or the same action as in the case of the large alluvial stream.

The fact that the bed of the Rio Grande is lowered during the period of floods, at least at certain points, is indicated by the cross sections shown on Figure 2. These cross sections represent the bed of the river under the Santa Fe Railroad Bridge at San Marcial in 1929. Some of the sections were taken during the large flood of that year. The stream is contracted to some extent here at high flows; and the presence of bridge piers, no doubt, increases the scour. The tendency of the bed to be deeper near the piers is evident on these sections. These piers are set at an angle with the direction of flow, which no doubt increases their scouring effect somewhat.

Discharge measurements have been made on the Colorado River at Yuma, Arizona, since 1878. The large amount of stream-bed lowering which occurs at this station during floods has received much publicity and has been partly responsible for the impression that the river bottom of such streams scour deeply at flood stage. Some of the flow cross sections for the years 1912, 1916, and 1929 are shown on Figure 4. In general, the maximum increase in depth at the section is about twice the rise in the water surface. These measurements were made by a cableway at a very narrow section of the river where one or both banks are of scour-resisting material. The bed material consists of very fine sand. Backwater curve studies made in connection with the determination of levee grades below Yuma, indicate that this degradation effect probably continues through a narrow stretch of the river which extends about 12 miles below Yuma.

In striking contrast with the large stream-bed degradation at the Yuma station was the situation at the site of the Imperial Dam. A cable station was operated at this location for a short period before the dam was constructed. During this period the flow reached a maximum of about 65,000 second-feet. Although the bottom shifted considerably, being higher first on one side and then the other, there was no appreciable change of the mean bottom level.

During the excavation for Hoover Dam, a sawed and planed 2- by 6-inch wood plank was found in the river-bed material 50 feet below low-water surface and 40 feet below the bottom of the river channel. This discovery indicated that at some comparatively recent time, the river in this canyon had scoured out the bed to the depth of this plank.

Figure 5 shows the cross sections at two stations on the Yellow River in China as described by J. R. Freeman. [4] These sections depict the degradation of the bed of this stream during a flood. The cross sections were taken at gaging stations where the river was probably narrow. At one of them, rock was exposed nearby on one bank. At two other stations for which sections were not given, Mr. Freeman observed a similar degradation. He apparently believed that the degradation was continuous along that part of the river covered by his studies. Cross sections of the Verde River near Fort McDowell, Arizona, which indicate a considerable degradation of this stream at high flows, are provided by Holmquist. [5] This gaging station is located at a point where the river runs between rock banks and is confined to a comparatively limited width.

An examination of the foregoing data shows that at most of the gaging stations mentioned, the bottom unquestionable recedes considerably at high flows. All of the cases where the bottom receded were located either, (1) at bridges where the presence of piers would induce scour, (2) stations where the river was narrow, or (3) where the stream was probably narrow since measuring stations are usually placed where the river is narrow. The only location where a stream had been measured from a cableway and where it was definitely known to be at a section which was not contracted, is on the lower Colorado River at the site of the Imperial Dam. At this point no stream-bed deepening was observed. We also have the proof from the volume of material carried into the Elephant Butte Reservoir that no great average depth of material is scoured from the Rio Grande bed in floods and carried into the reservoir. Proof of a similar conclusion is the fact that the concentration of sediment carried in most streams in floods is insufficient to account for the amounts excavated or refilled if the degradations indicated by measurements at most gaging stations are typical of the whole length and width of the river.

HOLMQUIST'S HYPOTHESIS

An explanation which is consistent with all the observed data, except that taken at the site of the Imperial Dam, is that the river behaves as described by F. N. Holmquist. [6] He believed that rivers of the type under discussion at flood stage excavate a deep channel over only a portion of their width, depositing the material excavated in the shallower portions of the channel a short distance downstream. This deep channel, he believed, tends to approach the outside of the bends; and, thus, in flowing downstream it may cross from one side of the river channel to the other. The channel constantly shifts its position usually by side erosion, but occasionally the shift may be by avulsion (a complete and sudden abandonment of a portion of its former course and adoption of a new channel).

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4. Flood Problems in China - J.R. Freeman - Trans ASCE Vol. 85, 1922, p.1436.
5. Behavior of Debris-Carrying Rivers in Flood - F. N. Holmquist, Engineering News Record, Vol. 94, February 26, 1925, pp. 362-365.
6. See previous reference.

OBSERVATIONS DURING THE 1948 FLOOD IN THE RIO GRANDE

After the foregoing studies were completed, an opportunity was had to observe, both from the ground and the air, the conditions during the flood in the Middle Rio Grande at the end of May 1948, at which time the flow at Albuquerque reached about 13,000 second-feet.

A special effort was made during these observations to determine the existence of a narrow, deep channel, such as that described by Holmquist; but no evidence was found of such a phenomenon. The fact that the location of bridges and gaging stations is nearly always at narrow sections of the river, however, was definitely established. The observations that these narrow sections scour out during floods agreed with the visual observations, which also strongly indicated that the material removed was deposited at the next wide section downstream and not carried on down the river. These observations are in agreement with all of the other observed data on the Middle Rio Grande, and this tends to confirm the accuracy of these observations.

This explanation also agrees with another condition which has been observed, namely, that the greatest danger to the levees along the Middle Rio Grande is from cutting of the banks, and this seems to be most active on the falling stages. It is believed that during the height of the flood, deposits occur in the wide, shallow sections. Because of the shallow depth, a channel may be very largely filled by a deposit of moderate depth, the volume of which was well within the ability of the stream to transport and lay down. Similarly a bar may be formed to a height which includes a considerable part of the depth of the flow. When the flood recedes, the bottom topography may be considerably different from that which existed at the start of the flood because of these deposits; and the former channels may be sufficiently blocked forcing the stream flow to follow new paths. If these paths happen to impinge on the bank when the flow decreases, a new and unexpected scour occurs which, under particularly unfavorable conditions, may have serious consequences. This is quite a different action from that which occurs on large alluvial rivers where the greatest bank cutting also occurs on a falling stage of the flood. In the case of the large river, this action is principally due to the softening of the bank and the outward pressure at the bottom of the banks due to the return of the seepage water to the river, as well as to the sloughing of the high banks of saturated material which are exposed as the water recedes. This action is not important on the Rio Grande since the rise of the water level during a flood is not large.

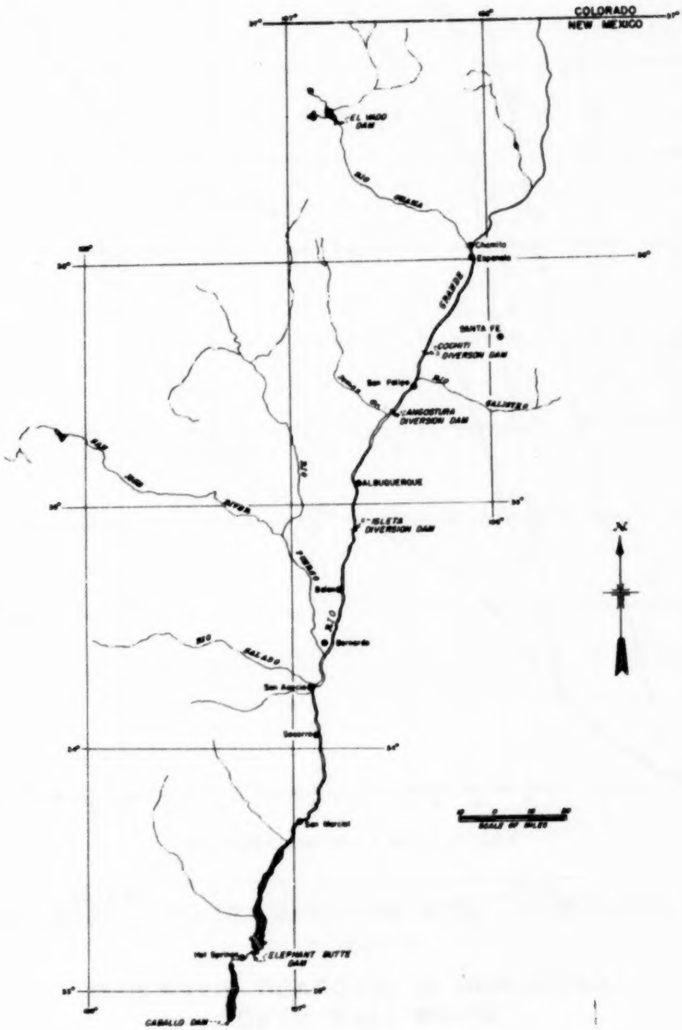
CONCLUSIONS

As a result of the studies previously described, it was concluded that during floods the bed of the Rio Grande, in general, scours out at the narrow sections and that most of the material thus removed is deposited in the next wide section downstream. This action causes the wide section to fill up somewhat and, at times, promotes channel changes in the wide sections which may cause the stream to attack the bank. It is believed that this action is typical of rivers of this type, which include most of the Great Plains rivers. It was also concluded that the widely held view that there is a general lowering of the bed of such streams during floods is unsound. The belief arises because the bottoms at gaging stations usually scour out, but such stations are usually located at bridges or cableways where the rivers are narrow, and are not typical of the greater part of the length of the river. The unsoundness of the

idea of a general lowering is proved by the lack of the volume of deposit in the Elephant Butte Reservoir which would result from such scour and by the lack of sufficient concentrations in the flowing water to carry such excavation away during the rising flood or to deposit it back in place as the flood recedes.

Although these general studies did not lead to a quantitative result on the average depth of scour of the Rio Grande bed during flood, they did prove that it was much less than generally believed by many experienced river men.

Acknowledgments: The writers wish to acknowledge helpful suggestions from Thomas Maddock, Jr. in the preparation of this paper.


COLORADO
NEW MEXICO
EL VADO DAM
Chamita
Espanola
SANTA FE
COCHITI DIVERSION DAM
San Felipe
ANGOSTURA DIVERSION DAM
ALBUQUERQUE
ISLETA DIVERSION DAM
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Bernardo
San Acacia
Socorro
San Marcial
Hot Springs
ELEPHANT BUTTE DAM
CABALLO DAM
SCALE OF MILES

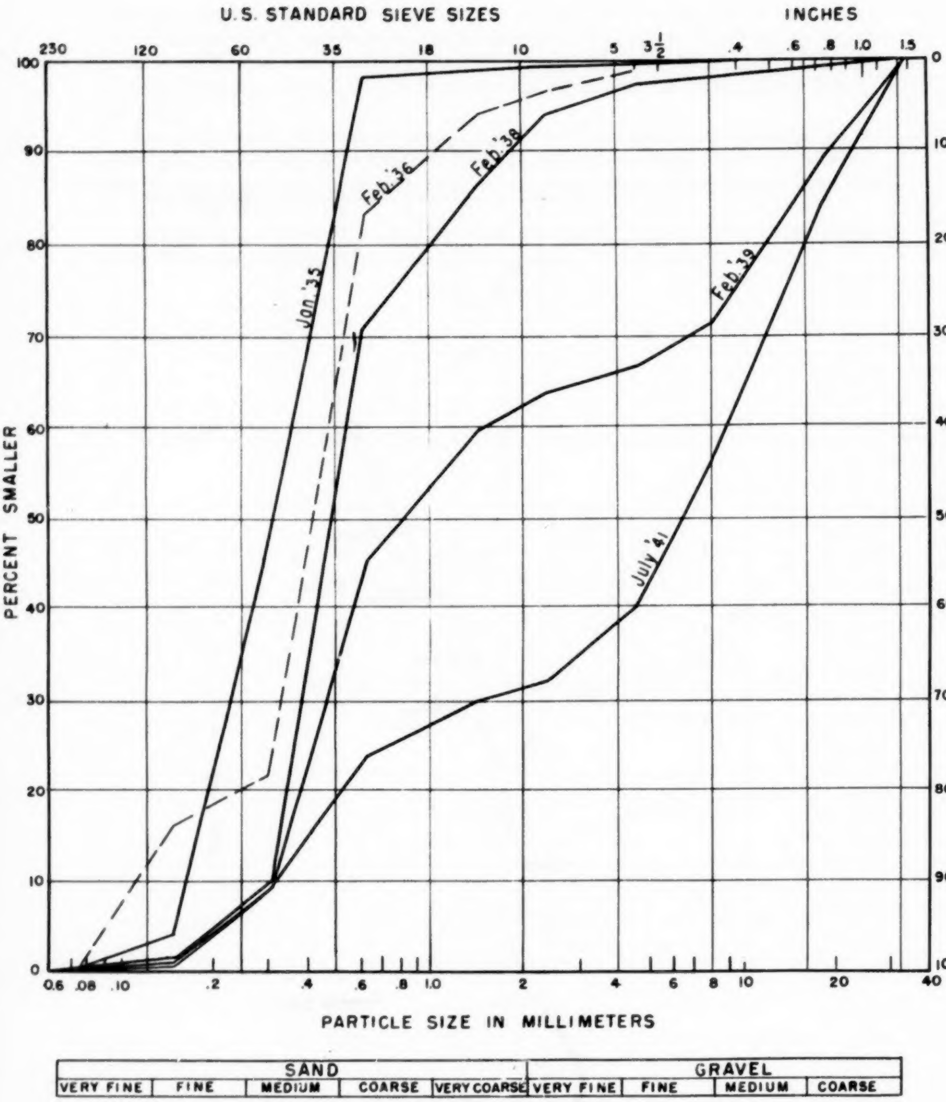


FIGURE I

COARSENING OF COLORADO RIVER BED
BELOW LAKE MEAD

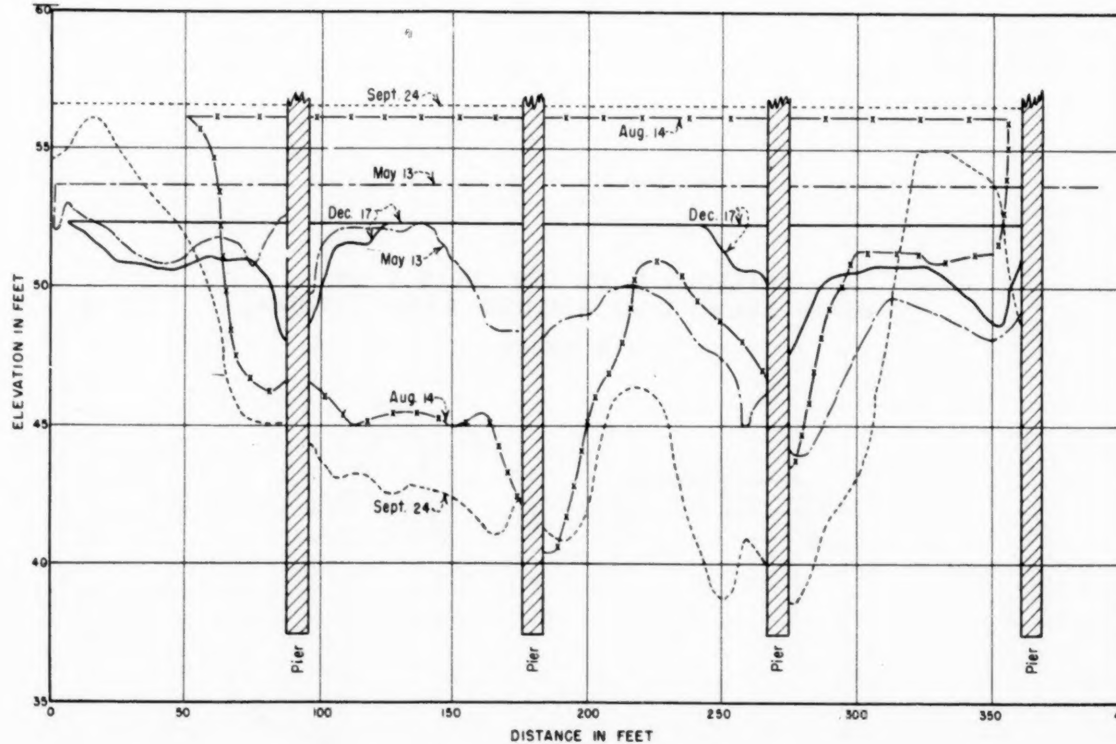


FIGURE 2

CHANGES OF RIO GRANDE CROSS SECTION
SAN MARCIAL, NEW MEXICO 1929

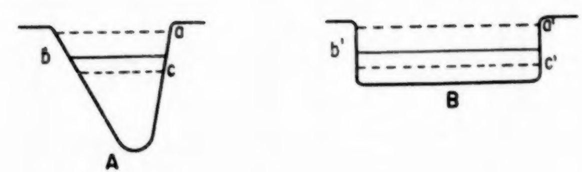


FIGURE 3

TYPICAL CROSS SECTION OF A LARGE RIVER
AT A BEND AND AT A CROSSING

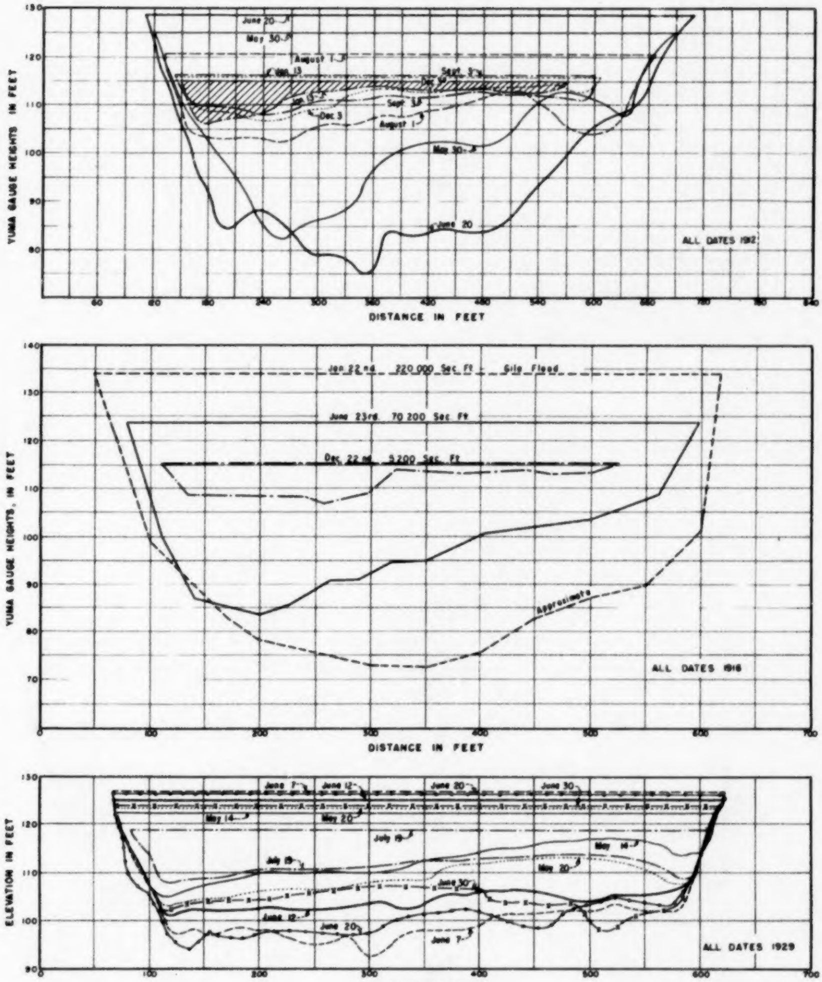
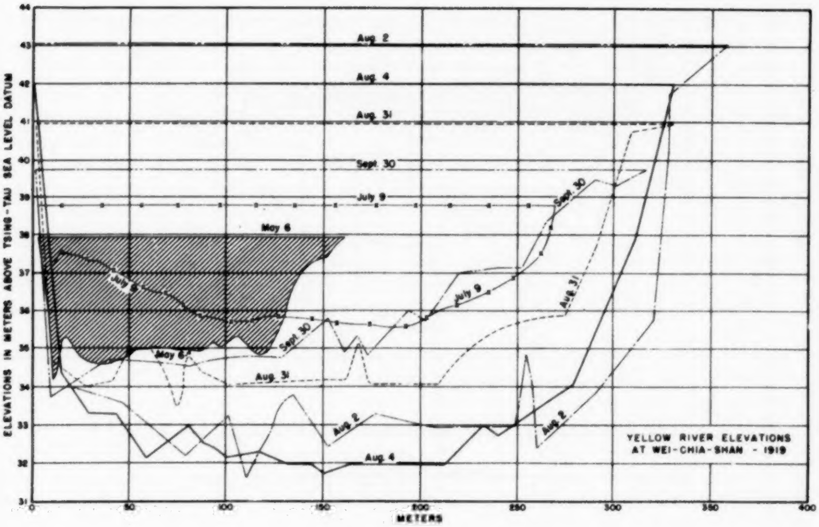


FIGURE 4

CHANGES OF COLORADO RIVER CROSS SECTION

YUMA, ARIZONA 1912, 1916 AND 1929



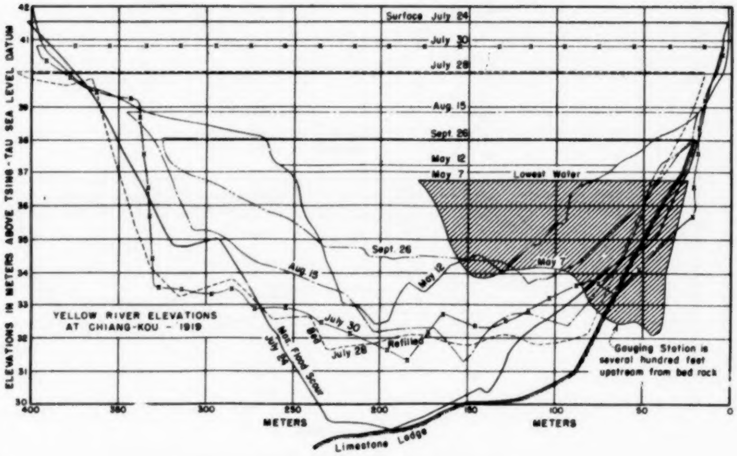


FIGURE 5

CHANGES OF YELLOW RIVER CROSS SECTIONS
WEI-CHIA-SHAN AND CHIANG-KOU, CHINA - 1919